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This reports covers the MODIS **cirrus characterization and correction** algorithm and part of the MODIS **near-IR water vapor algorithm.**

Main topics addressed in this time period:

1. **Level 2 and Level 3 file specifications for MODIS near-IR water vapor and thin cirrus products**: The Level 2 and Level 3 file specifications for MODIS near-IR water vapor and cirrus products have been defined and revised several times with the help from Allen Chu. The Level 2 cirrus product contains mainly two images - cirrus reflectance image and cirrus-reflectance-flag image. The cirrus reflectance image can be used by other MODIS investigators to remove cirrus path radiance effects from MODIS data. The cirrus-reflectance-flag image will indicate whether pixels in a scene are non-cirrus, cirrus, or aircraft contrail pixels. The Level 3 cirrus product contains four products - mean cirrus reflectance, mean contrail reflectance, cirrus area fraction, and contrail area fraction.

2. **Issues related to MODIS Ch. 18 and Ch. 26**: In early 1997, concerns were raised about possible problems with MODIS Ch. 26 and Ch. 18. The Ch. 26 is located near the center of the 1.38-µm water vapor band. Cross-talking to Ch. 26 from other MODIS channels was a concern for some time. Further test at SBRS under vacuum environment showed that the cross-talking is not a problem to Ch. 26.

   The digital number of Ch. 18 is typically only 43. Digitization noise will likely be introduced in calibrated MODIS data for this channel. Ch. 18, the very narrow water vapor absorption channel, was originally proposed by Dr. Al. Arking. The filter for this channel has far more layers of coating in comparison with other “broader” channels. The peak transmission for filter 18 is only about 0.3. As a result, little energy will be transmitted to the detectors. Gao proposed to increase the gain factor for this channel. After a number of E-mail exchanges, it is still not clear how the problem will be solved. The problem with Ch. 18 is still remaining at present.

3. **Algorithm Development** (*Han, Gao,, Chu, and Ridgway*) -

a. I/O interface routines - Allen Chu has made good progress with writing the I/O interface routines for both the MODIS near-IR water vapor algorithm and the thin cirrus algorithm. The final I/O interface routines are still not finished yet.

b. Cirrus algorithm - The 1.375-µm channel is affected by absorption from water vapor above and within cirrus clouds. The magnitude of the absorption depends on the amount of water vapor, the solar and view zenith angles. A lookup table has been produced for correction of angular dependencies. An empirical approach, similar to the one outlined in our MODIS cirrus proposal, will be implemented in our algorithm for estimating cirrus reflectances in the 0.4 - 1.0 µm region from the 1.375-µm channel.

Aircraft contrails resulted from commercial aircraft emissions may have radiative effects on the Earth's radiation budget. Detection of contrails from AVHRR and GOES data are practically difficult. Images of the 1.375-µm MODIS channel, which usually do not have surface and low level cloud contaminations, will be very useful for contrail detections during the day time. Bill Ridgway has made progress with the contrail detection algorithm. This algorithm is based on the Hough transformation, which identifies linear features in a two dimensional image. The detection algorithm seeks to create a "mask" image which identifies contrails within a two dimensional scene. The "input" image is the MODIS 1.38 micron radiance field, which is sensitive to solar backscatter sources in the upper troposphere, particularly clouds including thin cirrus and contrail features.

The contrail detection algorithm has been coded in FORTRAN 90 and proceeds in the following steps:

(i) A ridge detection algorithm is first applied to the brightness field. The algorithm scores individual pixels to produce a derived field which is sensitive to horizontal, vertical, and diagonal ridges. The ridge field to identify pixels of possible interest as part of a contrail.

(ii) The Hough transformation next maps all interesting ridge pixels within the brightness field onto curves within a new two dimensional space, that is, the space of all possible straight lines. The intersections of curves within this "Hough field" are points representing lines in the original image. A second threshold is applied to the "Hough field" in order to single out points which are common to many curves. These points correspond to lines in the brightness field along which many ridge pixels can be single out points which are common to many curves. These points correspond to lines in the brightness field along which many ridge pixels can be found. They are likely candidates as contrail segments.

(iii) Finally, a line length threshold is applied to guarantee that short bright ridge features are ignored in favor of longer linear features. The final output mask field is composed of line segments which meet this last threshold test.

To aid in the selection of appropriate thresholds, a series of histograms are computed for the radiance field, ridge pixel field, and Hough field. Cumulative histograms are used to adjust thresholds in each case. The algorithm succeeds in finding contrails in upward-looking images taking with a digital camera. We expect that thresholds will require adjustment for the distribution of pixel radiances typical of the MODIS 1.38 micron radiance field.

c. Near-IR water vapor algorithm - Our V1 MODIS near-IR water vapor algorithm assumed a two-way transmission model during the derivation of water vapor values from MODIS data. However, under hazy conditions and over dark surfaces, correction of aerosol effects is needed. Currently, a module using aerosol optical depths from Yoram Kaufman's MOD04 algorithm has been developed for correction of aerosol effects in our retrieved water vapor values.

Han modified a comprehensive atmospheric radiative transfer code (STRATS) to include rural and tropospheric aerosols. Then generated two lookup tables by running STRATS: (a) reflectance at 0.86 micron and (b) ratio of reflectance at 0.94 micron to 0.86 micron, as a function of column water vapor amount, aerosol optical depth at 0.55 micron, surface reflectance at 0.86 micron, solar and view zenith angles, and relative azimuth angle. The computation took over one month in computer time.

Currently, the MOD05 Version 2 algorithm for retrieving column water vapor amounts from MODIS data consists of three steps: (a) retrieve column water vapor amount value through a lookup table procedure from version 1 of MOD05, which relies on look up tables generated from pure gaseous transmittance calculations (not including aerosol effects), (b) compute a correction factor using looking up tables generated with STRATS in the case of dark surface (albedo < 0.1) or bright surface (albedo > 0.5) with aerosol optical depth in the visible greater than 0.5, (c) apply the correction factor to the water vapor amount value retrieved in step (a). Now the algorithm is pending for integration into the overall MODIS processing streams and further testing with synthetic MODIS data.

4. **Ice particle phase function calculations** - There are two scientific groups performing theoretical calculations of ice particle phase functions - Professor Liou's group at University of Utah, and Drs. Michael Mishchenko and Andrew Macke at NASA/GISS. The two groups do not necessarily agree with each other. Gao has made arrangements to provide partial support to both groups for their help in simulating ice particle phase functions. Dr. Liou's group has provided a comprehensive set of ice particle phase functions (including all the 36 MODIS channels). Mishchenko also provided a number of phase functions corresponding to different ice particle sizes. Mishchenko modified the standard geometric ray

optics technique to include Fraunhofer diffraction effects. After the modification, the delta-function transmission peaks in phase functions are reduced.

5. **Radiative transfer modeling** (*Wei Han, Gao, and Ridgway)* -

Our previous report has described progress with expansion of ice particle phase functions and improving DISORT. Further progress has been made. Now we can perform radiance simulations using DISORT with realistic ice particle phase functions for MODIS channels. This set of codes will be useful for sensitivity studies on our empirical approach for correction/removing thin cirrus effects from MODIS data.

The framework for the radiative transfer modeling of inhomogeneous thin cirrus cloud fields was also developed by Bill Ridgway. The centerpiece is a Monte Carlo simulation of scattered solar radiance based on (1) sun angle, (2) detector wavelength, position, orientation, and resolution, (3) spatially varying surface albedo and bi-directional reflectance function, (4) conservative Rayleigh scattering and non-conservative aerosol and cirrus scattering, and (5) absorption by atmospheric gases (primarily water vapor). The Monte Carlo algorithm is functional, but each of the components such as, for instance, the ice particle phase function or K-distributions representing single channel water vapor absorption are still under development. A FORTRAN code with simplified components was created as a starting point for the development.

6. **Data Analysis** (*Wei Han, Gao,*) - We have made additional analysis of AVIRIS and MAS data collected during the ARMCAS experiment conducted in June, 1995. Although surface features are seen in water vapor channels near 1.38 and 1.88 µm under the dry arctic conditions, we found from AVIRIS and MAS data that the 1.38 and 1.88 µm channels are still the best channels to detect thin clouds over arctic tundra (because of absorption by water vapor between clouds and the surface), while the IR emission channels and visible channels fail completely in detecting any clouds. We also found that cirrus clouds can be separated from water clouds based on the differences between the 1.66- and 1.73-µm images. The shapes of reflectance spectra for water clouds and ice clouds are different in this spectral region because of differences in water and ice refractive indices. A poster on this subject was presented during the AGU Spring Conference held in Baltimore in May, 1997.

7. **Execution Phase Work Plan** (*Gao,*) - Gao wrote an Execution Phase Work Plan for our proposed MODIS work, and gave a presentation on the work plan. A revision on the workplan was made based on comments from MODIS Project managers. The final plan was submitted to MODIS Project. Now our MODIS proposal has been approved by NASA for the execution phase of the EOS program.

Plans for the next 3 month:

(a): deliver the V2 MODIS near-IR water vapor and cirrus cloud algorithms to MODIS SDST, and help with the software integration.

(b): write a paper on cloud detection over polar regions based on our analysis of AVIRIS and MAS data acquired during the ARMCAS experiment, and submit the paper to Journal of Applied Meteorology.

(c): start the work of writing the technical document on our cirrus reflectance and aircraft contrail algorithms.

(d): work on the validation plan, particularly on plans for comparison between MODIS derived water vapor values and those from microwave radiometers and operational radiosondes.